PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01V 3/12 | A2

(11) International Publication Number: **WO 00/00849**

(43) International Publication Date: 6 January 2000 (06.01.00)

(21) International Application Number: PCT/NO99/00200

(22) International Filing Date: 17 June 1999 (17.06.99)

(30) Priority Data:
19982825 18 June 1998 (18.06.98) NO

(71) Applicants *(for all designated States except US)*: DEN NORSKE STATS OLJESELSKAP A.S [NO/NO]; N-4035 Stavanger (NO). NORGES GEOTEKNISKE INSTITUTT [NO/NO]; Postboks 3930, Ullevål Hageby, N-Oslo 0806 (NO).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: KONG, Fan-Nian [NO/NO]; Langbølgen 71, N-1150 Oslo (NO). WESTERDAHL, Harald [NO/NO]; Haugerås, N-2072 Dal (NO). EIDESMO, Terje [NO/NO]; Markapl. 5, N-7054 Ranheim (NO). ELLINGSRUD, Svein [NO/NO]; Tyholt allè 9A, N-7052 Trondheim (NO).

(74) Agent: ABC-PATENT, SIVILING. ROLF CHR. B. LARSEN A.S; Brynsveien 5, N-0667 Oslo (NO).

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published

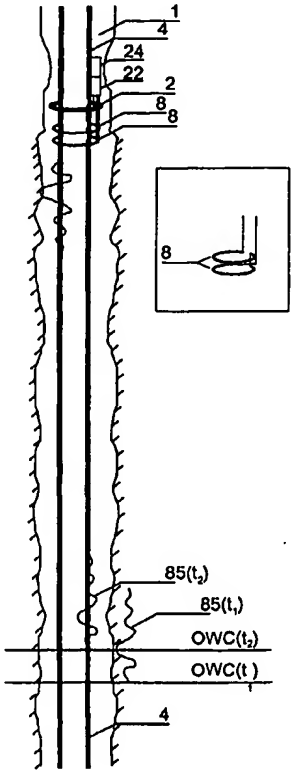
In English translation (filed in Norwegian).

Without international search report and to be republished upon receipt of that report.

(54) Title: DEVICE AND METHOD FOR MEASUREMENT BY GUIDED WAVES ON A METAL STRING IN A WELL

(57) Abstract

Device for detection of changes of resistivity or dielectrical properties due to changes of fluid compositions in the near-well area 0-500 m about a well (1) in a geological formation (9), comprising an electrically conductive tubing string (4), e.g. a liner pipe or an other fixedly arranged tube or openhole completion in the well (1). The characteristic by the invention is: a) an electrical energy source (24); b) a signal generator (22) for generation of electromagnetic signals (25) to; c) at least one transmitter antenna (2) for electromagnetic waves (26), arranged preferably above an oil/water contact, on a fixed first position on the tubing string (4), and arranged for essentially to guide the electromagnetic waves along the tubing string (4); d) one or more receiver antennas (8_1, 8_2, .., 8_n) for guided electromagnetic waves along the tubing string (4), arranged on other fixed positions along the tubing string (4); e) devices (80) for receiving of signals (85_1, 85_2, .. 85_n) induced in the receiver antennas (8_1, 8_2, .., 8_n) due to wave impedance gradients along the tubing string (4) in rocks or fluids in the geological formation (9) and in the electrically conductive tubing string (4); f) signal processing means (82) for processing of the received signals (85_1, 85_2, .., 85_n); g) communication devices (100, 200) for transmission of signals (105) representing the electrical signals (85_1, 85_2, .., 85_n), and for receiving control signals (205).



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

DEVICE AND METHOD FOR MEASUREMENT BY GUIDED WAVES ON A METAL STRING IN A WELL.

This invention relates to the topic of geophysical logging, particularly logging of a petroleum well by means of guided electromagnetic waves. What is being logged is electrical properties and changes in these, preferably in rocks situated along a metallic string in a drilled well.

Description of the situation.

The metallic string may be a drillstring or a production tubing. The electromagnetic parameter is the wave impedance between the electrically conductive string and the surroundings. The string's surroundings consist of a cylindrical cavity generally axially parallel with the string, and more or less porous and permeable geological (mainly sedimentary) layers of varying dielectrical permettivity combined with varying resistivity (conductivity). Due to their porosity the geological strata always contain more or less water. Sediments consisting of sandstones or carbonates have low electrical conductivity in their own, depending on the mineral composition, and schists have a somewhat higher electrical conductivity due to chemical composition and the ionic structure. Water is a polar liquid and may dissolve salts, e.g. NaCl, $CaCl_2$, NaFl which easily form ions Na^+, Ca^{2+}, Cl^- etc. This water is electrically conductive with resistivity roughly around 0,01 Ωm - 1 Ωm, depending on the amount of dissolved salt and the ionic valence. Oil and gas does not dissolve corresponding amounts of salt. Rocks containing oil or gas have much less electrical conductivity, thus larger resistivity, crudely estimated to be in the range of 10^1 Ωm-10^3 Ωm.

Statement of problem.

By production from a well is meant to take out liquids and gases. During production of an oil-bearing well one normally does not want to produce water. Due to the liquid density one will, in a liquid trap, e.g. a synform or a fault, encounter gas, oil and water as counted from above in

a petroleum-bearing zone in a well. The boundary surfaces in an undisturbed oil/gas/water zone are usually horizontal. The well may contain several petroleum-bearing zones. When taking out oil and gas the boundary surface between oil and water will rise. This boundary surface is called the oil/water contact, hereafter called the OWC: Oil/Water Contact. Due to the liquid not being entirely ideally fluid, but has a limited permeability in the porous rock, the OWC does not be horizontal, but more or less shaped as a curved surface. The shape of the liquid surfaces is determined by the relative viscosities for gas, oil and water and the local permeabilities in the rocks. It is desirable to monitor such liquid surfaces during production of oil or injection of water, natural gas, CO_2 or other fluids in the reservoir.

The known art.

Radar-similar detection in boreholes is known, both by means of pulsed electromagnetic waves and continuous coherent electromagnetic waves. The electromagnetic waves are generated by a signal generator and emitted by means of a rod-shaped or ring-shaped dipole antenna, e.g. fixed to a logging sonde lowered in the borehole. Such borehole radars are described in US-patent 5 530 359: "Borehole logging tools and methods using reflected electromagnetic signals", describing a directionally sensitive logging sonde having a transmitter antenna and several rod antennas arranged azimuthally about the sonde's vertical axis.

US-patent 4 504 833: "Synthetic pulse radar system and method" describes a "georadar" emitting pulsed signals consisting of a series of selected frequencies emitted simultaneously. The system is arranged for a mobile platform and is arranged for sending electromagnetic waves down into geological formations and for detecting electromagnetic waves being reflected from impedance contrasts inside the geological formations.

The patent publication expected to be closest to this invention is US-patent 5 552 786: "Method and apparatus for logging underground formations using radar" concerning a method to determine wave velocities for the radar waves

propagating from the transmitter antenna to the receiver antenna "directly" via the rocks being closest to the borehole. The wave velocities derived from the measurements between transmitter and receiver antenna (a few feet) is used for the geophysical interpretation of the geological structures around the borehole.

Definition of the invention; reference to the set of claims.

The above mentioned problems are solved by means of a device and a method according to this invention which in a preferred embodiment is a device for detection of changes in resistivity or dielectrical properties due to changes of fluid composition in the near-well area 0-500 m about a well 1 in a geological formation 9, comprising an electrically conductive tubing string 4, e.g. a liner pipe or other fixedly mounted tube or openhole completion in the well 1. The characterising by the invention is

a) an electrical energy source 24,

b) a signal generator 22 for generation of electromagnetic signals 25 to

c) at least one transmitter antenna 2 for electromagnetic waves 26, arranged preferably above an oil/water contact, in a fixed first position on the tubing string 4, and arranged for mainly to guide the electrical waves along the tubing string 4,

d) one or more receiver antennas ($8_1, 8_2, .., 8_n$) for guided electromagnetic waves along the tubing string 4, arranged in other fixed positions along the tubing string 4,

e) devices 80 for receiving signals ($85_1, 85_2, .., 85_n$) induced in the receiver antennas ($8_1, 8_2, .., 8_n$) due to wave impedance gradients along the tubing string 4 in rocks or fluids in the geological formation 9 and in the electrically conductive tubing string 4,

f) signal processing devices 82 for processing of the received signals ($85_1, 85_2, .., 85_n$),

g) communication devices 100, 200 for transmission of signals 105 representing the electrical signals ($85_1, 85_2, .., 85_n$), and for receiving control signals 205.

Additional features by the invention are defined in the enclosed patent claims and described in the detailed

description below.

Description of drawings.

Fig. 1 shows a view and partial section of a principle embodiment of the invention comprising a metallic tubing string with a transmitter antenna and two receiver antennas for guided electromagnetic waves.

Fig. 2 shows the same as Fig. 1, but here the metallic tubing string is replaced by a drillstring.

Figs. 3 and 4 display illustrations of resistivity logs which may be achieved by means of a device and a method according to the invention. Two graphs named "before" and "after" are shown in Fig. 3, with resistivity change arising due to displacement of the oil/water contact (OWC).

Detail description of an embodiment according to the invention.

Generally an embodiment of the invention is a device for detection of changes of resistivity or dielectrical properties due to changes of fluid compositions in the near-well area 0-500 m about a well 1 in a geological formation 9. In the well 1 an electrically conductive tubing string 4 is arranged, e.g. a liner pipe or an other fixedly arranged tube or an openhole completion. In Fig. 1 is illustrated a principle embodiment of the invention, comprising the following features:

a) An electrical energy source 24, for energy supply to a signal generator 22 and possibly an amplifier and to a transmitter antenna 2 and to other electrical equipment in the well being described below.

b) The signal generator 22 for generation of electrical signals 25 to the transmitter antenna 2.

c) At least one transmitter antenna 2 for electromagnetic waves 26, with the transmitter antenna 2 being arranged preferably above an oil/water contact, on a fixed first position on the tubing string 4, and arranged for mainly to guide the electromagnetic waves along the tubing string 4. In a preferred embodiment of the invention the transmitter antenna 2 or a prefabricated tubing string module (not shown) comprising the transmitter antenna 2 may be fixedly

cemented to the borehole wall in the well 1.

d) One or more receiver antennas ($8_1, 8_2, .., 8_n$) for guided electromagnetic waves along the tubing string 4, are arranged by other fixed positions along the tubing string 4. These receiver antennas may also in a preferred embodiment be present as preassembled modules before they are lead down in the well and fixedly cemented to the geological formation 9.

e) Devices 80 for receiving signals ($85_1, 85_2, .., 85_n$) induced in the receiver antennas ($8_1, 8_2, .., 8_n$) due to wave impedance gradients along the tubing string 4 in rocks or fluids in the geological formation 9 and in the electrically conductive tubing string 4. These wave impedance gradients along the tubing string 4 may have their cause in the spatial variation of resistivity as an intrinsic property of the geological strata and in pore fluids in the rocks, e.g. water containing larger or smaller quantities of salt, and oil. Due to the fact that the electromagnetic waves are guided along the tubing string 4 one may compare this with the metal core of a coaxial cable, and the geological formation around the tubing string 4 as being the dielectricum surrounding such a metal core int the coaxial cable.

f) Signal processing devices 82 for processing the received signals ($85_1, 85_2, .., 85_n$) may in an embodiment be arranged in the immediate vicinity of the receiver antennas ($8_1, 8_2, .., 8_n$). However the signal processing devices 82 may be arranged in a combined unit downhole in the well 1, or at the surface.

g) Communication devices 100, 200 for transmission of signals 105 representing the electrical signals ($85_1, 85_2, .., 85_n$), and for receiving control signals 205. These communication devices 100, 200 may transfer information about measurement signals from a petroleum reservoir in the geological formation 9 to the surface for interpretation of e.g. the oil/water contact and its movement. In alternative embodiments of the invention the signals 105 may be conducted to other downhole devices for controlling the production flow.

In a preferred embodiment of that the receiver antennas

($8_1, 8_2, .., 8_n$) are arranged with preferably even internal separation in a zone covering at least a part above the oil/water contact (OWC) and preferably down to the oil/water contact. In a preferred embodiment there is arranged a pair of receiver antennas ($8_1, 8_2$) by the top of the reservoir. Electromagnetic waves being emitted from the transmitter antenna 2 are guided along the tubing string 4 downward to the oil water contact. By the oil/water contact a reflection will be formed, which returns an electromagnetic wave 85. This wave 85 will be picked up by the receiver antennas ($8_1, 8_2$). The distance to the oil/water contact may be determined from a two-way travel time to the reflecting surface by determining a propagation velocity from resistivity logs and frequency. cancelling devices 8' by the receiver antennas ($8_1, 8_2, .., 8_n$) arranged for cancelling in the receiver antennas of the direct emitted signal from the transmitter antenna 2. The receiver antennas ($8_1, 8_2$) may be oppositely coupled and arranged to cancel the direct emitted electromagnetic wave 26. If the receiver antennas are coupled to cancel the direct wave the receiver antennas ($8_1, 8_2$) may be arranged to preferably receive reflected guided waves (85) travelling upwards the tubing string. The cancelling may be performed physically or take place as a subtraction in a data processing.

In an alternative embodiment, e.g. with an existing production well available, one may arrange the transmitter antenna 2 and the receiver antennas ($8_1, 8_2$) by the top of the production string. In this way one may apply a device according to the invention for surveillance of existing completed wells.

In a preferred embodiment the signal generator 22 is arranged to generate electrical signals 25 for emission of coherent continuous electromagnetic signals 26 from the transmitter antenna 2. In an additionally preferred embodiment the signal generator 22 is arranged for generation of electromagnetic signals to the transmitter antenna 2 for emission of coherent continuous electromagnetic waves 26 by a number of *i* different frequencies ($f_1, f_2, \ldots, f_i$) from the transmitter antenna 2. Emission of coherent continuous electromagnetic signals

implies that one avoids dispersion of the propagating electromagnetic signal due to phase spreading of the propagation velocities of the electromagnetic waves as function of the frequencies.

In alternative embodiments the signal generator 22 may be arranged to generate electrical signals to the transmitter antenna 2 for emission of frequency sweep electromagnetic signals 26.

In additionally alternative embodiments of the invention the signal generator 22 may be arranged for generating pulsed electrical signals 26, or other forms of modulation of electromagnetic signals, in the transmitter antenna 2. One must however bear in mind the limitations in the application of pulsed electromagnetic signals in a strongly dispersive medium with respect to frequency and phase velocity.

The signal processing devices 82 for processing of the received signals ($85_1, 85_2, .., 85_n$) are arranged for detecting gradients of the electromagnetic impedance in the geological formation 9. However a manual geophysical interpretation may be done, based on the received signals ($85_1, 85_2, .., 85_n$). A surveillance of the petroleum reservoir may be performed by means of that the signal processing devices 82 for processing of the received signals ($85_1, 85_2, .., 85_n$) are arranged for detecting *changes* of the gradients of the electromagnetic impedance about the tubing string 4 in the geological formation 9 between two points of time t_1 and t_2. Naturally this may also take place by observation of logs describing the resistivity development between the two points of time t_1 and t_2.

The transmitter antenna 2 comprises in a preferred embodiment an impedance adjustment device 2' arranged for adjusting the impedance of the transmitter antenna 2 to each particular of the emitted discrete frequencies (f_1, f_2, ..., f_i), for maximum energy emission in the form of guided electromagnetic waves along the electrically conductive tubing string 4. If the transmitter antenna in an alternative embodiment comprises a pulse transmitter, with the emitted electromagnetic pulse implying a broad frequency spectrum, the antenna must be designed so as to emit the

essential part of the energy out along the tubing string 4. As mentioned above, the pulse technique incurs phase dispersion of the propagation velocities in the medium.

In a preferred embodiment the antennas 2, 8 are arranged on or by the tubing string 4 inside the geological formation 9. As mentioned above there may, in a preferred embodiment, be such that at least one of the antennas 2, 8 be arranged by the earth's surface, preferably near the upper end of the tubing string 4, or for the sake far down on the tubing string 4.

In a preferred embodiment it will for frequencies below about 10 MHZ be applied electrical coils as receiver antennas ($8_1, 8_2, .., 8_n$) arranged around the tubing string 4. For higher frequencies above 10 MHZ is it proposed to apply dipole antennas as receiver antennas ($8_1, 8_2, .., 8_n$) arranged outside of the outer metallic surface of the tubing string 4. By 10 MHZ the wavelength in the rocks is between 2 and 4 metres, depending on the resistivity, thus a quarter-wave antenna becomes about 0.5 to 1 metre of length.

Clearly the invention may work with only one receiver antenna instead of 2 or n receiver antennas ($8_1, 8_2, .., 8_n$).

In an alternative embodiment the transmitter 2 and the receiver antennas ($8_1, 8_2, .., 8_n$) may be arranged on a module of a drillstring. Thus the invention may be applied for measurement while drilling, so-called MWD. Then the reflected waves 85 will change while the drillstring works downward through strata of varying resistivity and dielectrical properties.

On the background of the above mentioned it is according to the invention two possible methods, one method with the antennas is arranged on a fixed, i.e. under normal conditions a fixed production tubing, and an other method with the antennas arranged on a drillstring. In the first method one will be enable to search for the oil/water contact and its movements. In the second method one may as mentioned above be able to investigate the electrical properties in the rocks being penetrated by the drillbit.

In a preferred embodiment the invention is a method for detecting changes in resistivity or dielectrical properties due to changes in fluid compositions in the near-well area

0-500 m around an electrically conductive tubing string 4 in a well 1 in a geological formation 9.

The method comprises the following steps:

i) Emission of a first series of electromagnetic waves 26_1 along the tubing string 4 from a transmitter antenna 2 at a first fixed position in the well 1, at a first point of time t_1.

ii) Reception of a first series of guided electromagnetic waves ($85_1, 85_2, .., 85_n$) at receiver antennas ($8_1, 8_2, .., 8_n$) at second fixed positions in the well 1 by the tubing string 4, and transformation of the first series of reflected electromagnetic waves ($85_1, 85_2, .., 85_n$) to first registrations S_1.

iii) Emission of a second series of electromagnetic waves 26_2 along the tubing string 4 from the transmitter antenna 2 at the first fixed position at a later second point of time t_2, with the time difference $t_2 - t_1$ typically being several hours, days or longer time. The purpose of this second emission is to monitor displacements and changes of electrical properties in the well and the geological formations 9 as mentioned above.

iv) Reception of a second series of guided electromagnetic waves ($85_1, 85_2, .., 85_n$) at the receiver antennas ($8_1, 8_2, .., 8_n$) at the second fixed positions by the tubing string 4 at the later second point of time t_2, and transformation of the second series of reflected electromagnetic waves ($85_1, 85_2, .., 85_n$) to second registrations S_2.

v) Forming of a difference D_{t2-t1} by subtraction of the first registrations S_1 from the second registrations S_2, and interpretation of the difference D_{t2-t1} as a distance to a change of electromagnetic impedance caused by a displacement of a liquid horizon or liquid front, e.g. an oil/water contact OWC.

The points (iii) to (iv) and (v) may be repeated as many times as desirable. The method may be performed by an operator or by an algorithm which may be situated in downhole processing equipment.

In a preferred embodiment the method comprises that the points (i) and (iii) comprises generation of coherent continuous electromagnetic signals 26_1 and 26_2 from the

transmitter antenna 2. In an additionally preferred embodiment according to the invention incorporates generation of electromagnetic waves 26_1 and 26_2 at a number of *i* different frequencies f_1, f_2, ..., f_i from the transmitter antenna 2.

Cancelling in the receiver antennas ($8_1, 8_2, .., 8_n$) of the emitted direct signal 25 from the transmitter antenna 2 is performed by cancelling devices 8' as mentioned above during the description of the device according to the preferred embodiment.

Impedance adjustment of the transmitter antenna 2 is performed adapted to each particular of the discrete frequencies f_1, f_2, ..., f_i being emitted, for maximal energy propagation with the electrically conductive tubing string 4. Corresponding tuning or impedance adjustment of the receiver antennas ($8_1, 8_2, .., 8_n$) is performed for each particular of the discrete frequencies (f_1, f_2, ..., f_i) being emitted, for maximum energy reception of the reflected electromagnetic waves along the electrically conductive tubing string 4.

Of the received signals ($85_1, 85_2, .., 85_n$) there is formed at least one discrete (Fourier-) frequency spectrum of at least two of the parameters amplitude $A(\omega)$, phase $\Phi(\omega)$, amplitude of the real part $Re(\omega)$, amplitude of the imaginary part $Im(\omega)$, with ω corresponding essentially to those frequencies (f_1, f_2, ..., f_i) which were emitted from the transmitter antenna 2. This frequency spectrum may be formed by means of sampling of the received signal series $85_1(t)$, $85_2(t)$, ..., $85_i(t)$ and following transformation to the frequency domain. An alternative is to measure received amplitude $A(\omega)$ and phase $\Phi(\omega)$ for each received signal series $85_1(t)$, $85_2(t)$, ..., $85_i(t)$ directly, and thus build up a frequency spectrum directly on the frequencies (f_1, f_2, ..., f_i).

On use of discrete continuous waves, an inverse Fourier transform $F(\omega) \rightarrow f(t)$ may be performed on at least two of the parameters amplitude $A(\omega)$, phase $\Phi(\omega)$, amplitude of the real part $Re(\omega)$, amplitude of the imaginary part $Im(\omega)$, with ω corresponding essentially to those frequencies (f_1, f_2, ..., f_i), which were emitted from the transmitter antenna 2, in

order to form a time series f(t) representing pseudo-reflexes formed by electromagnetic impedance gradients in the geological formation (9). Other analysis methods may also be applied for analysing the measurements $85_1(t)$, $85_2(t)$, ..., $85_i(t)$. The information on OWC-displacement may be applied in "smart" wells for controlling the production process or enter as parameters which shall enter into a reservoir model which in turn is applied for controlling the production from an entire reservoir with many wells.

An alternative method is according to the invention applied during logging of electrical properties in a geological formation 9 during drilling of a well 1. The method comprises a repeated series of the following steps:

i) Emission of a first series of guided electromagnetic waves 25_1 along the tubing string 4 from a transmitter antenna 2 arranged outside the drilling string's 4 metallic surface, at a first point of time t_1;

ii) Reception of a first series of reflected electromagnetic waves ($85_1, 85_2, .., 85_n$) by at least one, preferably more receiver antennas ($8_1, 8_2, .., 8_n$) arranged outside the drillstring's 4 metallic surface, and transformation of the first series of reflected electromagnetic waves ($85_1, 85_2, .., 85_n$) to registrations S_1;

iii) Drawing up the registrations S_1 as a log of change of electromagnetic impedance caused by resistivity and permittivity in the strata of the geological formation 9 being penetrated as the drilling of the well 1 takes place.

A preferred method according to the invention comprises continuous surveillance of the registrations S_1 during drilling in order to detect that the drillstring's 4 lower end is approaching an electrically conductive horizon, e.g. an oil/water contact (OWC).

The same techniques for application of continuous coherent waves 26 may be applied as mentioned above. In the same way the antennas may be tuned and there may be performed a cancelling of the direct wave in order for better to detect reflected guided waves from the end of the drillstring, and to have a better utilization of the dynamic range in the signal processing.

C l a i m s

1. Device for detection of changes of resistivity or dielectrical properties due to fluid compositions in the near-well area 0-500 m around a well (1) in a geological formation (9), comprising an electrically conductive tubing string (4), e.g. a liner tubing or other fixedly arranged tube or openhole completion in the well (1),
c h a r a c t e r i z e d b y
a) an electrical energy source (24),
b) a signal generator (22) for generation of electromagnetic signals (25) to
c) at least one transmitter antenna (2) for electromagnetic waves, arranged preferably above an oil/water contact, in a fixed first position on the tubing string (4), and arranged for mainly to guide the electrical waves along the tubing string (4),
d) one or more receiver antennas ($8_1, 8_2, .., 8_n$) for guided electromagnetic waves along the tubing string (4), arranged in other fixed positions along the tubing string (4),
e) devices (80) for receiving signals ($85_1, 85_2, .., 85_n$) induced in the receiver antennas ($8_1, 8_2, .., 8_n$) due to wave impedance gradients along the tubing string (4) in rocks or fluids in the geological formation (9) and in the electrically conductive tubing string (4),
f) signal processing devices (82) for processing of the received signals ($85_1, 85_2, .., 85_n$),
g) communication devices (100, 200) for transmission of signals (105) representing the electrical signals ($85_1, 85_2, .., 85_n$), and for receiving control signals (205).

2. Device according to claim 1,
c h a r a c t e r i z e d i n t h a t
the receiver antennas ($8_1, 8_2, .., 8_n$) are arranged with internal separation in a zone covering at least a part above the oil/water contact (OWC) and preferably down to the oil/water contact.

3. Device according to claim 1,
c h a r a c t e r i z e d i n t h a t
the signal generator (22) is arranged to generate electrical

signals (25) for emission of coherent continuous electromagnetic signals (26) from the transmitter antenna (2).

4. Device according to claim 3,
c h a r a c t e r i z e d i n t h a t
the signal generator (22) is arranged for generating electrical signals to the transmitter antenna (2) for emission of coherent continuous electromagnetic waves (26) at a number of *i* different frequencies (f_1, f_2, ..., f_i) from the transmitter antenna (2).

5. Device according to claim 1,
c h a r a c t e r i z e d i n t h a t
the signal generator (22) is arranged for generating electrical signals to the transmitter antenna (2) for emission of frequency sweep electromagnetic signals (26).

6. Device according to claim 1,
c h a r a c t e r i z e d i n t h a t
the signal generator (22) is arranged to generate pulsed electromagnetic signals (26), or other forms of modulation of electromagnetic signals (26), in the transmitter antenna (2).

7. Device according to one of the preceding claims,
c h a r a c t e r i z e d i n t h a t
the signal processing devices (82) for processing of the received signals (85_1,85_2,.., 85_n), are arranged to detect gradients in the electromagnetic impedance in the geological formation (9).

8. Device according to one of the preceding claims,
c h a r a c t e r i z e d i n t h a t
the signal processing devices (82) for processing of the received signals (85_1,85_2,.., 85_n), are arranged to detect *changes* in the gradients in the electromagnetic impedance around the tubing string in the geological formation (9) between two points of time t_1 and t_2.

9. Device according to claim 1,
c h a r a c t e r i z e d b y
cancelling devices (8') by the receiver antennas (85_1,85_2,.., 85_n) arranged for cancelling in the receiver antennas of the emitted direct signal (26) from the transmitter antenna (2).

10. Device according to one of the preceding claims,
c h a r a c t e r i z e d i n t h a t
the transmitter antenna (2) comprises an impedance adjustment device (2') arranged for adjusting the transmitter antenna's (2) impedance to each particular of the discrete frequencies
(f_1, f_2, ..., f_i) being emitted, for maximal energy propagation of guided electromagnetic waves along the electrically conductive tubing string (4).

11. Device according to claim 1,
c h a r a c t e r i z e d i n t h a t
the antennas (2, 8) are arranged on or by the tubing string (4) inside the geological formation (9).

12. Device according to claim 1,
c h a r a c t e r i z e d i n t h a t
at least one of the antennas (2, 8) is arranged by the earth's surface, preferably near the upper part of the tubing string (4).

13. Method for detection of changes of resistivity or dielectric properties due to changes of fluid compositions in the near-well area 0-500 m around an electrically conductive tubing string (4) in a well (1) in a geological formation (9),
c h a r a c t e r i z e d i n that it comprises the following steps:
i) emission of a first series of electromagnetic waves (26_1) along the tubing string (4) from a transmitter antenna (2) at a first fixed position in the well (1), at a first point of time (t_1);
ii) reception of a first series of guided electromagnetic waves (85_1,85_2,.., 85_n) at receiver antennas (8_1,8_2,.., 8_n) at

second fixed positions in the well (1) by the tubing string (4), and transformation of the first series of reflected electromagnetic waves ($85_1, 85_2, .., 85_n$) to first registrations (S_1);

iii) emission of a second series of electromagnetic waves (26_2) along the tubing string (4) from the transmitter antenna (2) at the first fixed position at a later second point of time (t_2), with the time difference $t_2 - t_1$ typically being several hours, days or longer time;

iv) reception of a second series of guided electromagnetic waves ($85_1, 85_2, .., 85_n$) at the receiver antennas ($8_1, 8_2, .., 8_n$) at the second fixed positions by the tubing string (4) at the later second point of time (t_2), and transformation of the second series of reflected electromagnetic waves ($85_1, 85_2, .., 85_n$) to second registrations (S_2);

v) forming of a difference (D_{t2-t1}) by subtraction of the first registrations (S_1) from the second registrations (S_2), and interpretation of the difference (D_{t2-t1}) as a distance to a change of electromagnetic impedance caused by a displacement of a liquid horizon or liquid front, e.g. an oil/water contact OWC.

14. Method according to claim 13,
c h a r a c t e r i z e d i n t h a t
the steps (i) and (iii) comprise generation of coherent continuous electromagnetic signals (25_1) and (25_2).

15. Method according to claim 14,
c h a r a c t e r i z e d i n
generation of electromagnetic signals (25_1) and (25_2) by a number of *i* different frequencies f_1, f_2, ..., f_i.

16. Method according to claim 13,
c h a r a c t e r i z e d i n
cancelling in the receiver antennas ($8_1, 8_2, .., 8_n$) of the emitted direct signal (25) from the transmitter antenna (2) by means of cancelling devices (8').

17. Method according to claim 15,
c h a r a c t e r i z e d b y

impedance adjustment of the transmitter antenna (2) to each particular of the discrete frequencies (f_1, f_2, ..., f_i) being emitted, for maximal energy propagation with the electrically conductive tubing string (4).

18. Method according to claim 15,
c h a r a c t e r i z e d b y
impedance adjustment of the receiver antennas (8_1,8_2,.., 8_n) to each particular of the discrete frequencies (f_1, f_2, ..., f_i) being emitted, for maximum energy reception of the reflected electromagnetic waves along the electrically conductive tubing string (4).

19. Method according to claim 13 or 15,
c h a r a c t e r i z e d i n t h a t
of the received signals (85_1,85_2,.., 85_n) there is formed at least one discrete Fourier frequency spectrum of at least two of the parameters amplitude $A(\omega)$, phase $\Phi(\omega)$, amplitude of the real part $Re(\omega)$, amplitude of the imaginary part $Im(\omega)$, with ω corresponding essentially to those frequencies (f_1, f_2, ..., f_i) which were emitted from the transmitter antenna (2).

21. Method according to claim 20,
c h a r a c t e r i z e d i n t h a t
there is performed an inverse Fourier transform $F(\omega)\rightarrow f(t)$ of at least two of the parameters amplitude $A(\omega)$, phase $\Phi(\omega)$, amplitude of the real part $Re(\omega)$, amplitude of the imaginary part $Im(\omega)$, with ω corresponding essentially to those frequencies (f_1, f_2, ..., f_i) which were emitted from the transmitter antenna (2), in order to form a time series f(t) representing pseudo-reflexes formed by electromagnetic impedance gradients in the geological formation (9).

22. Method for logging of electrical properties in a geological formation (9) during drilling of a well (1)
c h a r a c t e r i z e d i n t h a t
it comprises a repeated series of the following steps:
i) emission of a first series of electromagnetic waves (26_1) along the drillstring (4) from a transmitter antenna

(2) arranged outside the drillstring's (4) outer metallic surface, at point of time (t_1);
ii) reception of a first series of reflected electromagnetic waves ($85_1, 85_2, .., 85_n$) by at least one, preferably more receiver antennas ($8_1, 8_2, .., 8_n$) arranged outside the drillstring's (4) outer metallic surface, and transformation of the first series of reflected electromagnetic waves ($85_1, 85_2, .., 85_n$) to registrations (S_1);
iii) drawing up the registrations (S_1) as a log of change of electromagnetic impedance caused by resistivity and permittivity in the strata of the geological formation (9) being penetrated as the drilling of the well (1) takes place.

23. Method according to claim 22
c h a r a c t e r i z e d i n
continuous surveillance of the registrations (S_1) in order to detect while drilling that the drillstring's (4) lower end approaches an electrically conductive horizon, e.g. an oil/water contact (OWC).

24. Method according to claim 22,
c h a r a c t e r i z e d b y
emission of coherent continuous electromagnetic signals (26_1, 26_2).

25. Method according to claim 22 or 24,
c h a r a c t e r i z e d b y
emission of coherent continuous electromagnetic signals (26_1, 26_2) by a number of *i* different frequencies (f_1, f_2, ..., f_i).

26. Method according to claim 23,
c h a r a c t e r i z e d b y
cancelling in the receiver antennas ($8_1, 8_2, .., 8_n$) of the emitted direct signal (26) from the transmitter antenna (2) by means of cancelling devices (8').

27. Method according to claim 25,
c h a r a c t e r i z e d b y

impedance adjustment of the transmitter antenna (2) to each particular of the discrete frequencies (f_1, f_2, ..., f_i) being emitted, for maximal energy propagation along the electrically conductive tubing string (4).

28. Method according to claim 25,
c h a r a c t e r i z e d b y
impedance adjustment of the receiver antennas ($8_1, 8_2, .., 8_n$) to each particular of the discrete frequencies (f_1, f_2, ..., f_i) being emitted, for maximum energy reception of the reflected electromagnetic waves along the electrically conductive tubing string (4).

29. Method according to claim 23 or 25,
c h a r a c t e r i z e d i n t h a t
of the received signals ($85_1, 85_2, .., 85_n$) there is formed at least one discrete Fourier frequency spectrum of at least two of the parameters amplitude $A(\omega)$, phase $\Phi(\omega)$, amplitude of the real part $Re(\omega)$, amplitude of the imaginary part $Im(\omega)$, with ω corresponding essentially to those frequencies (f_1, f_2, ..., f_i) which were emitted from the transmitter antenna (2).

30. Method according to claim 23,
c h a r a c t e r i z e d i n t h a t
there is performed an inverse Fourier transform $F(\omega)->f(t)$ of at least two of the parameters amplitude $A(\omega)$, phase $\Phi(\omega)$, amplitude of the real part $Re(\omega)$, amplitude of the imaginary part $Im(\omega)$, with ω corresponding essentially to those frequencies f_1, f_2, ..., f_i which were emitted from the transmitter antenna (2), in order to form a time series f(t) representing pseudo-reflexes formed by electromagnetic impedance gradients in the geological formation (9).

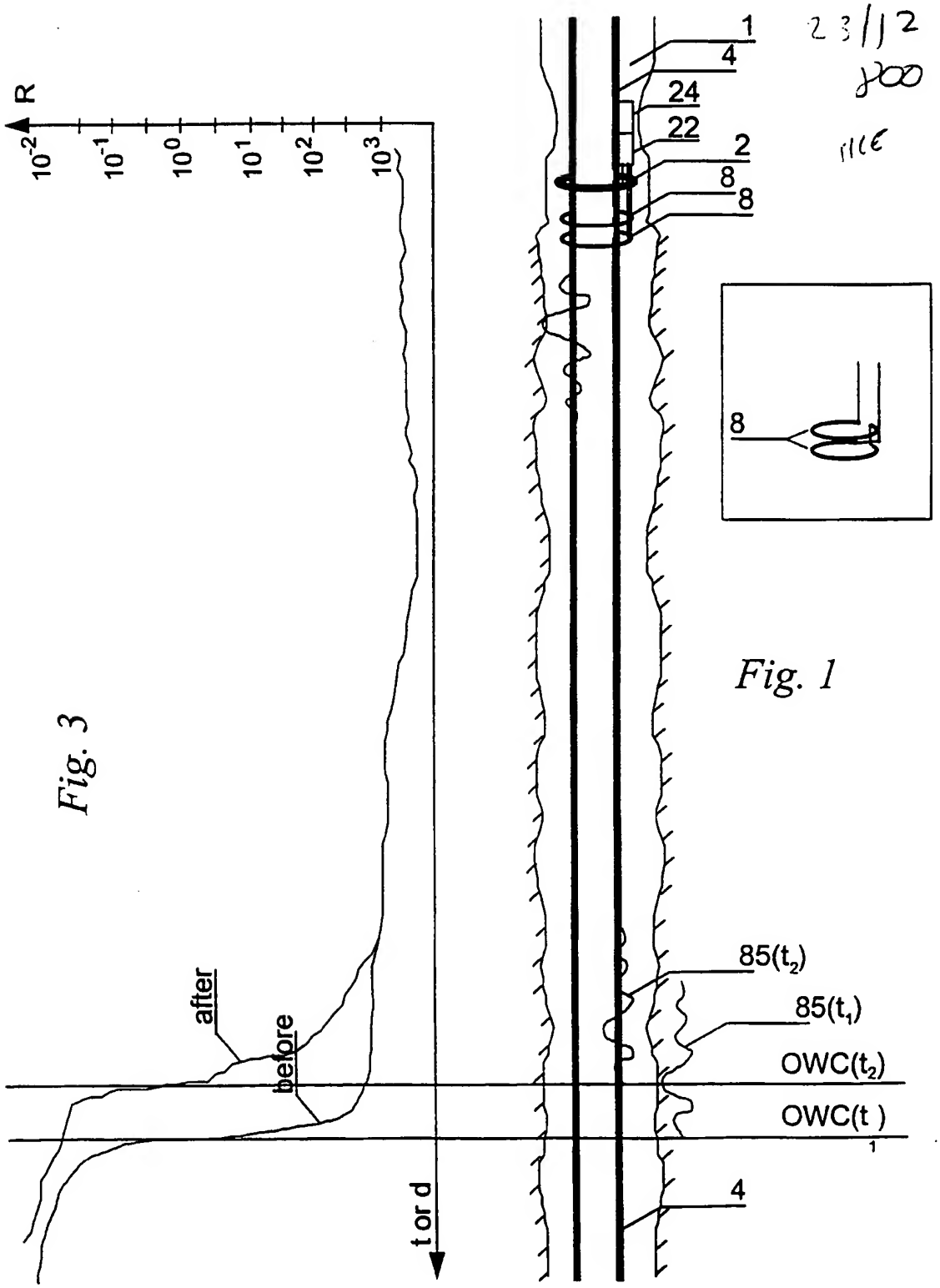

R
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
after
before
t or d
1
4
24
22
2
8
8
8
85(t_2)
85(t_1)
OWC(t_2)
OWC(t_1)
4

Fig. 3

Fig. 1

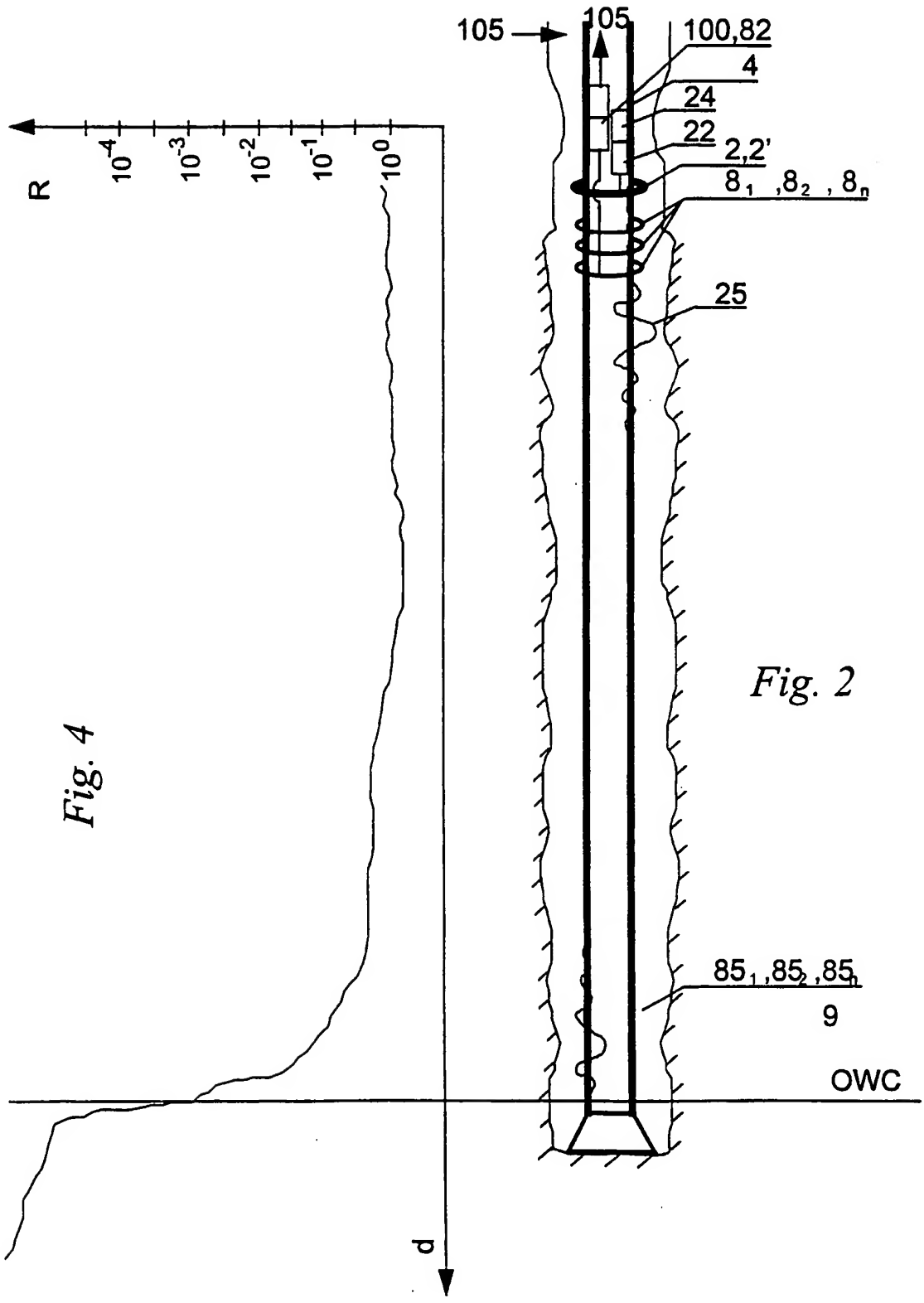

105
105
100,82
4
24
22
2,2'
8_1 ,8_2 , 8_n
25
85_1,85_2,85_n
9
OWC
R
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
d

Fig. 2

Fig. 4